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WEATHER FORECASTING - CONTROL

by

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WEATHER FORECASTING AND CONTROL

ORBITING of earth's first weather satellite on April 1 gave man a spectacular new instrument to aid in forecasting, perhaps controlling, conditions that importantly affect agriculture, industry, and the daily life of humankind. The two television cameras carried by Tiros I have been sending back to ground stations unexpectedly clear pictures of cloud cover over various parts of the globe. When Tiros I is joined by other, more advanced orbiting companions, the broad range of new information thus made available will greatly expand knowledge of weather-making forces. Meteorologists presumably will be able then to make more accurate and longer-range forecasts; rainmaking and other efforts by man to generate the kind of weather he wants may produce increasingly certain results.

Dimensions in weather research are vast. The earth's area of 197 million square miles forms the base of an enveloping blanket of atmosphere that is from 400 to 600 miles thick. It has been pointed out that "If all the persons in the world were weather watchers, each would have to watch about 2,000,000 tons of atmosphere." [1] The atmosphere comprises hundreds of air masses, each with its own surface characteristics of temperature, humidity, cloudiness and visibility, its own vertical structure and "life cycle." As these masses move across land or sea, they acquire new characteristics. Hence there is question whether any key to complex weather patterns can be found in neat mathematical formulas.

Meteorologists are confident, however, that it will be possible some day to make order out of the seeming atmospheric disorder. Even a small improvement in long-range weather forecasting would produce economic savings of millions of dollars for agriculture and industry. Weather modification on a local or regional basis might bring relatively large benefits at modest cost. Large-scale weather

[1] George H. T. Kimble, "Storm Clouds Over Weather Control," *New York Times Magazine*, Feb. 9, 1958, p. 69.

modification projects, such as the thawing of Arctic ice recently proposed by Soviet scientists, conceivably could change the climate of whole continents. Vannevar Bush, chairman of the Office of Scientific Research and Development in World War II, has expressed both the hope and the challenge of this search for effective control of weather processes:

> It is entirely possible, were he wise enough, that man could produce favorable effects, perhaps of enormous practical significance, transforming his environment to render it more salutary for his purposes. This is certainly a matter which should be studied assiduously and explored vigorously. The first steps are clear. In order to control meteorological matters at all we need to understand them better than we now do. When we understand fully, we can at least predict weather with assurance for reasonable intervals in the future.[2]

Bush urged in conclusion: "By all means let us get at it."

Weather Lessons of the Geophysical Year

International Geophysical Year studies provided a rich source of meteorological data for scientists seeking keys to long-range forecasting and weather control. Sixty-six nations participating in the 18-month-long enterprise, which ended Dec. 31, 1958, took measurements of temperature, pressure, wind speed and direction, humidity, precipitation, solar radiation, ozone, carbon dioxide, and natural and artificial atmospheric radioactivity. As a result of I.G.Y. the first daily weather maps of the entire globe were prepared for two levels—sea level and 20,000 feet. Oceanographic studies, particularly the finding and measuring of three major counter-currents, gave scientists new insight into the role of the oceans in formation of weather. Oceanographers found the Antarctic Ocean to be the only place in the world where circumpolar currents could exist without being deflected or stopped by land masses. These currents are believed to play a critical part in Antarctic weather, which in turn probably influences circulation of the atmosphere throughout the Southern Hemisphere.

Scientists discovered the existence of a high-altitude stream of electric energy girdling the equator, a Southern Hemisphere jet stream, and a trigger-like connection between "flare-ups" on the surface of the sun and jitters in

[2] Statement, Dec. 2, 1957.

the earth's atmosphere. Ice measurements in Antarctica, where 90 per cent of the world's ice is accumulated, required upward revision of the world total by at least 40 per cent—a finding of importance in connection with studies of the delicate balance of the earth's heat and water budget. On the other hand, the scientists ascertained that the floating ice of the Arctic was one-third thinner and covered a considerably smaller area than it did 60 years ago.

RESEARCH BY ROCKETS AND SATELLITES; TIROS I

Development of rockets and satellites has given scientists new tools to probe the mysteries of weather processes. About 300 rockets were fired into and above the atmosphere on I.G.Y. projects to measure air pressures, densities, temperatures and wind speeds. The United States announced on April 6 that government scientists were now setting up a network of weather rocket stations to check atmospheric conditions up to 40 miles above the earth—twice as high as weather balloons can reach. The idea was tested for a month, Jan. 18 to Feb. 19, with daily rocket firings from Wallops Island, Va., and Point Mugu, Calif., and other firing stations are to be added. Daily launchings in all four seasons of the year are planned. Soviet scientists have perfected a recoverable and reflyable rocket for more or less routine soundings to measure air pressures, densities, and temperatures up to an altitude of 35 miles, and have taken detailed measurements for Antarctic, Arctic and Middle European locations.

Balloon tests remain of importance in high-altitude research. I.G.Y. emphasis on higher soundings led to development of a high-performance balloon that reached an average height of 107,180 feet in 24 tests, about 37,000 feet higher than in prior balloon experiments. The Army announced, Feb. 11, 1959, that an experimental weather balloon had set a new altitude record of 146,000 feet, close to 28 miles, and in the process had shown important temperature variations in the upper atmosphere.

Rockets and balloons have narrow utility when compared with the potentialities inherent in a system of weather satellites. First efforts by the United States to perfect such a system concentrated on satellites capable of taking pictures of cloud cover conditions. Crude cloud scanners

were flown in Vanguard II, launched Feb. 17, 1959, and in Explorer VI, orbited Aug. 7, 1959. In the case of Vanguard II, the cloud data, obtained by photo-cell technique, were jumbled by motion of the satellite and defied comprehensive reduction. Elementary television pictures of cloud formations were taken successfully by Explorer VI.

The first artificial satellite able to provide detailed photographs of the earth's cloud cover was Tiros I.[3] Its cameras have been taking pictures of cloud patterns from an altitude of about 450 miles. The pictures are stored on magnetic tape until "read-out" stations in Hawaii and Fort Monmouth, N. J., extract them. Photographs of weather formations in a 7,000-mile-wide belt around the earth are expected to be provided eventually. Scientists were jubilant about the clarity and detail of the Tiros pictures, but still were uncertain how to fit the wealth of new data into a world forecasting system.

Lack of geographical coordinates on many of the pictures received from the satellite was reported hampering efforts to relate the pictures to actual forecasting. The National Aeronautics and Space Administration announced on April 4 that the weather pictures obtained from Tiros I and future meteorological satellites would be shared with the rest of the world as an aid to preparation of global weather forecasts. International cooperation in the use of satellite weather information is likely to be carried on through the World Meteorological Organization, an agency of the United Nations.

Meteorologists believe that Tiros and the meteorological satellites to follow ultimately will usher in an era of practical forecasting from satellite data. Weather men envision a system of five or six satellites in polar orbits, and another satellite orbiting from west to east in the region of the equator (for use in detection of hurricanes and other tropical weather phenomena). Television cameras in the satellites presumably will be able to supply forecasters with a cloud map of the world every two hours and at the same time make observations of solar radiation, heights and thicknesses of cloud layers, precipitation, and temperatures in the stratosphere, troposphere, cloud tops, and at the surface.[4]

[3] The name "Tiros" stands for Television and Infra-Red Observation Satellite.

[4] The stratosphere is that part of the atmosphere above an elevation of 7 miles; the troposphere is that part of the atmosphere below the stratosphere.

Harry Wexler, director of meteorological research for the U.S. Weather Bureau, told a Senate Aeronautical and Space Sciences subcommittee, April 8, 1959, that such a satellite system would "help keep track of global climate, find out whether the climate is warming or cooling for the earth as a whole, determine the amount of solar radiation that goes into energizing storms, and, last but not least, it may give us such improved understanding of the atmosphere and its ways that it may open the way for some form of large-scale weather modification." Wexler asserted also that use of satellites "promises probably to be the biggest means of improving weather forecasts that has been developed for generations." After the firing of Tiros I, Wexler commented: "We've suddenly gone from rags to riches overnight."

Tiros I is regarded as essentially an experimental satellite, as one step on the way toward a final operational system. A second and more advanced Tiros is planned for launching this summer or early in the autumn. In addition to optical cameras, it will use infra-red equipment to measure atmospheric radiation. Weather satellites of Project Nimbus, which may make actual forecasting from satellite data possible, are looked for in 1962.

Progress in Long-Range Forecasting

SCIENTISTS familiar with the vagaries of the atmosphere consider the task of long-range weather forecasting one of the hardest in all meteorological endeavor. The public is frequent witness to the fact that weather forecasts for no more than 24 hours in advance often turn out to be inaccurate. The problem is immensely more difficult when it comes to trying to foresee weather patterns for longer periods.

Progress has been slow but definite since the first concerted scientific program of research on long-range weather prediction began in the mid-1930s. Disastrous drought in the central plains of the United States was responsible for exploration of the possibility of predicting dry spells. Clues to future weather were sought first in the readily visible picture of storms and lower atmosphere air movements, but

these proved to be "as chaotic as the eddies in a shallow river flowing over a rough bottom." Maps of airflow at ground level offered few clues even when averaged over a whole month. But a similar averaging of air movements at higher levels, from 10,000 to 40,000 feet, showed long waves or undulations, usually superimposed on a general west-to-east flow of air. The core of the long wave is the jet stream, generally between 30,000 and 40,000 feet, where currents may reach a velocity of 300 miles an hour. The long waves were found to be the principal mechanism for deploying the major air masses over the earth from their sources in the polar and tropical regions.

Meteorologists discovered that, once they could determine the pattern of long waves and of the flow of the upper air, it was possible to forecast temperatures for a week or a month ahead. No objective methods have been developed for satisfactorily interpreting contour patterns in terms of precipitation; unlike temperature, precipitation is an intermittent element and cannot be as precisely predicted far in advance.

Five-day forecasts, started in September 1940, predict the weather for each of the five succeeding days. No such detail is attempted in 30-day forecasts; they outline the principal expected paths of low and high pressures. Forecasts of expected average temperature in the 30-day forecasts, begun in January 1946, are expressed in terms of above or below normal. Normal is the average temperature for the particular month over the preceding 30 years. Precipitation is described in these forecasts as light, moderate, or heavy.

The 30-day forecasts have been as prone to error as to success. A prediction on Jan. 16, 1960, of above-normal temperatures for much of the South, including all of Florida, until mid-February went wrong within a week. A prolonged cold spell began then and damaged Florida vegetable and citrus fruit crops.

Outlook for Dependable Long-Range Forecasts

Weather Bureau meteorologists concede that present extended forecasts are at best rough sketches of possible weather conditions. Samplings on which the forecasts are based are small in terms of the vast cloak of atmosphere surrounding the earth. Charts of circulation in the upper

air go back 20 years, not long enough, meteorologists say, to set long-term trends. The charts are incomplete in many cases; much of the European data has been available only since the end of World War II. Great areas of the Pacific, breeding ground for a large part of the nation's weather, are almost untapped.

Francis W. Reichelderfer, Chief of the U.S. Weather Bureau, has said that present sampling of the atmosphere for purposes of weather analysis and forecasting is less than 5 per cent, perhaps less than 1 per cent, of the coverage needed to satisfy the requirements of increasingly complex operations and techniques in aeronautics, agriculture, and many other human activities vitally influenced by weather and climate. Jerome Namias, head of the Weather Bureau's extended-forecast section, has said that networks of observation stations "may have to be so dense to make detailed predictions that we may never be able to afford them." [5] Namias is "rather pessimistic" about ever getting a fully dependable forecast for each city on a day-by-day basis for a month in advance. Another weather expert has said:

> Precise prediction of the weather cannot be achieved, at least in the foreseeable future. As we continue to advance the meteorological science, it becomes evident that our increased ability to observe and analyze the atmosphere is not always accompanied by a corresponding improvement in the skill with which we are able to predict its future course.[6]

The Weather Bureau has been experimenting for the past five years with 90-day forecasts. Results, however, have not been sufficiently reliable to warrant publication. Unreliable forecasts quickly become targets of criticism. Complaints from Florida tourist interests that the Weather Bureau's 30-day hurricane forecasts, started in 1957, were hurting business are believed to have played a part in the Weather Bureau's decision to discontinue the forecasts after only one year. Sen. Spessard L. Holland (D Fla.) criticized Bureau officials for "predicting 45 possible hurricanes, of which not one materialized." Statements on hurricanes now are published only after the storms form and show direction. Meteorologists have had little success in trying to predict tornadoes more than 24 hours in advance.

[5] Interview in *U.S. News & World Report*, July 13, 1959, p. 58.

[6] Jack C. Thompson, executive assistant to deputy chief of U.S. Weather Bureau, speech to American Meteorological Society, Chicago, March 26, 1959.

Hope for considerable improvement in forecasting of hurricanes and tornadoes was raised on April 10, when a picture received from Tiros I showed a hurricane east of Australia. Reichelderfer said that sighting of the storm by the weather satellite indicated that "Hurricanes spawned anywhere over vast oceanic areas can be detected much earlier than ever before possible." The Weather Bureau chief said the event also gave "hope that, with future weather satellite camera systems, man will be able to solve the tornado observation problem in 'tornado alley' of the United States."

Proficiency in extended forecasting remains a long-range aim of meteorologists, but emphasis at present within the Weather Bureau appears to be on refinement of the 24-hour and 48-hour forecasts. The Bureau and the Federal Aviation Agency awarded contracts last year to develop a new electronic computer system and automatic observation stations that would cut by one-third or more the present interval of as much as six hours between observation of atmospheric phenomena and release of forecasts. A new radar storm-warning network that eventually will blanket the United States is in process of installation. Thirty-one of these radar stations, each capable of spotting severe weather within 250 miles, are expected to be in operation by July.

A prompt and accurate weather forecasting system is of special benefit to the Air Force and to commercial airlines, which need detailed weather data, particularly for high altitudes, on which to base flight plans. Advent of the jet age brought with it a mounting demand for information on temperatures and winds at high altitudes where jets seek out the coldest possible areas, to save fuel consumption, and where the jet air streams cut travel time. The Weather Bureau in 1959 began making wind-speed forecasts for up to 40,000 feet; previously, forecasts had not been made for altitudes above 20,000 feet.

Solar Activity Theory of Extended Forecasting

Meteorologists long have speculated on the possibility of finding a master key to the forces that set the atmosphere into motion and so the basis for accurately forecasting the weather for a season ahead or for an even longer period. In recent years considerable attention has been given to the sun and its radiation. Scientists at the University of

Colorado High Altitude Observatory at Boulder published a study in 1959 indicating that giant solar eruptions greatly intensify most of the cold fronts in the United States and move them farther south than they normally would extend. Maps of jet-stream pressure areas at 30,000-foot altitudes were correlated with solar eruptions over a period of three years. The scientists found that the jet streams shift south, after solar "dust" thrown off by the eruptions hits the earth, and drag with them cold fronts from the Arctic. The results of this inquiry are highly tentative, but research into sunspot activity might be of great value if correlations between such activity and the weather could be established on a scientific basis.

C. G. Abbot, formerly secretary of the Smithsonian Institution, believes that there is a definite relation between variations in solar radiation and weather conditions. Measuring the fluctuations in radiation, he developed a theory that moisture and temperature trends run in precise cycles of 273 months. To test the theory, he worked out "forecasts" of precipitation for past periods on this basis and found that they compared favorably with records of actual rainfall.[7] Most meteorologists think that observed fluctuations in the earth's supply of heat from the sun, which Abbot asserts are periodic, are too small (1/20 to 1/4 of 1 per cent) to affect the weather appreciably. But Abbot contends that once he found a weather cycle that corresponded with the solar variations, it no longer mattered whether the effects he ascribed to the radiation were actually of solar origin. He simply assumed that the weather cycle would recur, and that it would be possible to forecast weather far into the future.

The Smithsonian Institution on March 22 published a new report by Abbot in which he made forecasts of rainfall through 1967 for 32 cities. The forecasts state the exact expected departures from normal rainfall in each month. Abbot hopes these long-range predictions will prove at least 60 per cent accurate. In a previous experiment in which he "forecast" precipitation in St. Louis for a past period of 100 years, comparison with records showed that 70 of the years yielded "high correlation coefficients with the events." The failure of the other 30 could be "reasonably explained," Abbot said in his 1955 report, because

[7] C. G. Abbot, *Solar Variation, A Leading Weather Element* (Smithsonian Miscellaneous Collections, Vol. 122, No. 4, 1953), p. 35.

almost all of these unsatisfactory intervals fell "either when tremendous volcanic eruptions occurred or when there was tremendous use of explosives in war or explosions of atomic bombs." Abbot holds that high columns of vapor and dust thrown into the air by such occurrences profoundly modify weather conditions.

Special Needs and the Work of Private Services

Special requirements of industry and commerce for weather forecasting services have resulted in the rise of the commercial weather man. Hundreds of concerns now hire their own meteorologists to interpret forecasts in terms of their respective needs, and, in some cases, to work on aspects of long-range forecasting outside the Weather Bureau's scope of operation. Oil industry meteorologists, for example, seek more and better weather information on a seasonal basis. The petroleum industry has estimated that $100 million annually could be saved if the accuracy of seasonal forecasting could be improved by 10 per cent, since production and distribution requirements could then be met more efficiently. Prediction of water levels is important to establishments which rely on power from rivers and reservoirs. Contractors planning to pour concrete want to know whether it will rain or freeze. Bakers are concerned about levels of humidity. A growing number of private plane owners need detailed weather reports.

It has been estimated that about 15 per cent of the 7,000 meteorologists in the United States—compared with only 2 per cent a few years ago—now work for industry or are self-employed. Irving P. Krick Associates of Denver, the country's largest private forecasting and weather modification firm, has 100 employees. Most of the private weather men limit their forecasts to the short term, but a few will supply day-by-day predictions for years ahead.[8] Some claim a higher percentage of accuracy in forecasting than is commonly attributed to the Weather Bureau. In many cases, however, the private forecaster relies on Weather Bureau data; he simply interprets the data in terms of his client's interests.

A unique private weather research center is operated

[8] Krick contends that forecasts for one year ahead are capable of defining on any day 60 to 70 per cent of weather abnormalities in relation to seasonal normals. He resigned from the American Meteorological Society in 1958 in protest over a statement it issued in 1957 asserting that "Forecasts for more than one month in advance mislead the public if they do not clearly describe the forecasts as experimental and of unproven value."

by the Travelers Insurance Co. of Hartford, Conn. Forecasts are made available to the general public over the company's radio and television stations and by telephone. Special meteorological information compiled by the center helps Travelers to reduce losses, fix rates, and examine long-term climate conditions in areas where the company holds farm mortgage loans.

In the opinion of the company's meteorologists, the usual method of forecasting does not give the public full benefit of the weather information the forecaster has at his disposal. For example, when a meteorologist prepares a weather forecast, he is usually faced with several alternatives. If, in his judgment, the chances of rain are only 5 out of 10, he is likely to predict rain if for no other reason than that he has learned that a mistaken forecast of rain is less likely to irritate the public than a mistaken prediction of clear weather.

Travelers thinks it more logical to express the degree of uncertainty about the weather in a given forecast—a "probability forecast." The Travelers weatherman may issue a forecast like this: "Cloudy and cold today. The high near 40 degrees. Probability of snow flurries: 3 out of 10." This means the forecaster expects it to be cloudy and cold—with no snow. The chances are 7 out of 10 in favor of his forecast of dry weather, but it leaves 3 chances out of 10 for the possibility of snow flurries.

Probability forecasting is acknowledged by the Weather Bureau to be more meaningful to industrial and agricultural interests than the "decision type" of forecast currently in general use. Uncertainty over its acceptability to the public at large, objections voiced by special business interests who resent any "unnecessary" mention of rain,[9] and technical difficulties encountered in scientifically assigning a percentage figure to the probabilities have forced the Bureau to use the system cautiously. Probability forecasts now are going to the public through the Weather Bureau on an experimental basis in Los Angeles and San Francisco, where the "decision type" of forecast is followed by a probability breakdown. If public reaction is favorable, the Bureau will extend this type of forecast as rapidly as possible to other areas.

[9] Car wash firms in particular contend that any mention of a possibility of rain hurts their business.

Efforts of Man to Control Weather

WEATHER MODIFICATION in the United States has been considered only in local terms; proposals for changing weather on a continental scale have received little consideration, primarily because the climate in the well settled parts of the country is generally mild and wet. The Soviet Union, on the other hand, would seem to have much to gain by large-scale weather modification, for 47 per cent of its soil or subsoil is permanently frozen. Periodic droughts plague other portions of the vast Russian land mass, striking hard blows at an economy in which agricultural production even in good-weather years fails to meet consumer demand. Much of the discussion about changing weather on a large scale accordingly has been of Soviet origin.

American meteorologists report, however, that most of the Soviet talk has been confined to statements in the popular press. Scientific journals published by the Russians give the subject scant attention. The U.S. Weather Bureau has said that scientists in other countries are "on the whole less optimistic about large-scale weather control and public expectations are less speculative than in this country." [10]

The Bureau has concluded that Soviet attempts, if any, to control the weather on a large scale have yielded unsatisfactory results. Small-scale experiments in cloud seeding to produce rain, and in sprinkling coal dust on snow-covered fields to speed thawing, have been carried out in Russia but are regarded as not applicable to large-scale weather control within the foreseeable future. A Soviet expert has said that "At present the best scientific device in this field is the umbrella." [11] He added that the large amount of energy required for rain-making on an extensive scale would make such projects uneconomic.

The first nation learning how to control the weather may be able to cause flooding rains or searing drought over

[10] U.S. Weather Bureau, *A Summary Report on Progress and Possibilities in Weather Modification* (prepared at request of Senate Select Committee on National Water Resources, October 1959), p. 31.

[11] Statement by Prof. Aleksandr M. Obukhov, Director of the Institute of Physics of the Atmosphere, Soviet Academy of Sciences, at press conference, New York City, July 20, 1959.

vast areas. The potential threat of "meteorological warfare" has been acknowledged, but scientists are highly skeptical about the possibility of ever being able to direct destructive weather changes against a specific country.

Large-Scale Weather Modification Proposals

Proposals for large-scale weather changes are as ingenious as they are numerous. Scientists have suggested construction of great dams to deflect warm ocean currents toward the shores of arid lands, thus giving a source of evaporation of moisture which might be carried by the winds and provide more rain over the land. Dyestuff scattered over great expanses of the tropical oceans has been advanced as a means of increasing absorption of the sun's rays, warming the water and causing increased evaporation. One scheme envisions towing large ice floes northward from Antarctica as a means of moderating the frigid climate of that land mass. Covering polar ice with carbon black and other materials to absorb radiation and induce thawing has been suggested. Egypt has been reported considering a project to channel Mediterranean water into vast marshes below sea level in its western desert; evaporation presumably would double rainfall in the region.

A Soviet engineer, N. Romanov, was quoted by *Tass* last Dec. 20 as proposing the building of a tidal pump and dam across a five-mile stretch of water dividing the mainland of the Soviet Union from the island of Sakhalin. Romanov said the project should warm up thousands of miles of the Pacific coastline of Asia and banish snow from Japan forever. Pumps at tidal time would bring the warm current from the south, now dissipated in the Sea of Japan, into the icy waters of the Okhotsk Sea, and the dam would prevent the cold northern waters from penetrating south.

A related plan was proposed in October 1959 by Pyotr Borisov, another Soviet engineer. He advocated joint erection by the United States and Russia of a reinforced concrete "floating" bridge 46 miles across Bering Strait between Alaska and the Soviet Union's Chukotski Peninsula. Huge pumping stations would draw cold water from beneath the Arctic ice, diverting the cold Labrador and Greenland currents of the North Atlantic and drawing the warm Gulf Stream through the Arctic Ocean from the Atlantic to the Pacific. In time the Arctic ice would thaw and open water would absorb the warmth of the sun's rays.

Borisov was quoted as saying that once the ice was melted and the deep frost dissipated, "the whole shore of the Arctic Ocean in January will be approximately the same temperature as the Ukraine and ships will be able to navigate throughout the entire year." Gov. William A. Egan of Alaska, 70 per cent of whose land is subject to perpetual frost, was sufficiently interested to request that the State Department look into the proposal. The Department asked various scientific societies to study the project.[12]

Serious Risks in Attempting to Change Climate

Some scientists are apprehensive lest the "cures" to be effected by large-scale weather modification projects turn out to be worse than the ailments. Tempering the present Arctic climate, for example, might prevent winter storms from moving as far south, but it might also turn heavily populated sections of the United States into arid areas. Another concern of scientists is the possibility that thawing five million square miles of ice might trigger great snowstorms that would usher in a fifth ice age.

According to a theory expounded by Maurice Ewing and William L. Donn in 1956, cold air traveling southward across the heated water not only would grow warmer but also would absorb a great deal of water vapor, because the capacity of air to hold water increases rapidly as temperature rises. When the moist air reached land to the south, a part of the moisture would be discharged in the form of snow. If snowfall increased by as much as three or four feet, the annual deposit would exceed the annual loss from melting and evaporation and a new ice age might follow.

The Ewing-Donn theory puts in question the advisability of carrying out other proposals aimed at melting Arctic ice. One of these calls for explosion of hydrogen bombs beneath the surface of the Arctic Ocean to send steam gushing into the atmosphere and produce conditions leading to increased temperatures, reduced accumulations of ice, and eventual melting of the ice pack. Even if it is assumed that Arctic ice could be thawed without creating adverse climatic changes, the logistics involved might stand in the way. It has been estimated that it would take 1.5 billion tons of carbon black to cover the Arctic ice pack

[12] The State Department suggested that the Borisov project might form an appropriate subject of discussion at the meeting next July in Helsinki, Finland, of the International Union of Geodesy and Geophysics.

and adjacent snow fields to promote melting. And it would take 100 million sorties by Globemaster cargo planes to lay down one billion tons of carbon black.[13]

Probably only the thinner ice of the Arctic, on the order of 10 feet thick, would be susceptible to this treatment. The icecaps of Greenland and Antarctica are one to two miles thick. Thawing of Arctic ice might raise the level of the oceans enough to submerge many of the world's major port cities. If Antarctic ice also could be and were thawed, the sea level might rise by as much as 200 or 300 feet, according to estimates based on ice measurements made during the International Geophysical Year in 1957 and 1958.

Proposals to evaporate more water from the oceans entail the danger that increased humidity might add to the number of destructive hurricanes, tornadoes and hailstorms. Large-scale shifts in the rainfall pattern, moreover, while benefiting some regions, might deprive others of their water resources. Many meteorologists believe that circulation of the air is too strong and steady to be affected by the puny forces man can exert. Conversely, some researchers contend that the atmosphere is basically unstable and that small forces might set off chain reactions capable of altering weather patterns.

Possible Sources of Unplanned Weather Changes

Man has had little success so far in attempts to modify or control weather, but certain of his normal activities may have had modifying effects. Some scientists assert that recent warming of the earth can be attributed to an increase in the carbon dioxide content of the atmosphere, which itself may have resulted from the great increase in oxidation of carbon by combustion of fuels for domestic and industrial purposes during the past century. Carbon dioxide has absorption characteristics that prevent escape of the sun's radiated heat back into space and thus cause the earth's surface to grow gradually warmer. Temperature records for the past 50 to 100 years indicate fairly conclusively that the earth has been getting warmer, owing primarily to warmer winters, at a rate equivalent to about two degrees Fahrenheit in a century. "Small as this may seem to be, it is believed, by the supporters of the CO_2

[13] Harry Wexler, "Modifying Weather on a Large Scale," *Science*, Oct. 31, 1958, p. 1059.

school, to be quite capable of turning the usual [weather] into the unusual." [14]

Heat and blast effects from nuclear devices, particularly in the tropical zones of unstable weather, have been viewed as a possible source of unintended changes in the equilibrium of the atmospheric system.[15] Heat from the fires set by the atomic bomb at Hiroshima in 1945 is known to have produced numerous showers in the moist air overlying the city, and the base surge of the underwater Bikini shot in 1946 also led to formation of showers that lasted for 20 to 30 minutes. Debris and dust particles suspended in the air for long periods after nuclear blasts are believed capable of inducing large-scale, long-term weather changes by shifting the radiation and heat balances of the atmosphere.

Concern over possible effects of nuclear tests on weather reached a peak in the mid-1950s, when much of the United States was gripped by drought and numerous tornadoes occurred. But two meteorologists, after studying all available data, concluded that there was "no reason for believing that any past atomic explosion at the Nevada proving ground had any significant effect on the weather more than a few miles from the test site." [16]

Results of Rain-Making Efforts in United States

More than six times as much water flows across the continental United States in the air as is carried by all the country's great rivers. The water in the air, however, is a resource whose utilization until recently was subject to the caprices of nature. Modern scientific rain-making started in 1946 when Vincent J. Schaefer, a General Electric scientist, dropped dry ice into a cloud over the Berkshire hills of Massachusetts and thereby apparently brought about ensuing precipitation.[17]

Since that time, many thousands of field tests, involving seeding of clouds with one or another of several agents, have been carried out in hundreds of localities. After a

[14] George H. T. Kimble, "Why the Weird Weather?" *New York Times Magazine*, Oct. 26, 1958, p. 15.

[15] The theory that explosions and noise are capable of changing the weather dates back many centuries. Plutarch in the first century connected the noise of battle with subsequent rains, and the development of gunpowder several centuries later gave rise to the theory that concussion could induce condensation in the atmosphere.

[16] L. Machta and D. L. Harris, "Effects of Atomic Explosions on Weather," *Science*, Jan. 21, 1955.

[17] See "Weather Modification," *E.R.R.*, 1953 Vol. II, pp. 729-744.

decade of experimentation, however, "the direct evidence of success in inducing rain to fall in large quantity by artificial means was disappointingly small." [18] Commercial weather men concede that their rain-making business has fallen off in recent years, to some extent because of the uncertainty of the results.

An undercurrent of pessimism about weather modification runs strong among independent investigators. The Weather Bureau has been both praised and blamed for taking a conservative stand on the subject; its attitude is said to derive in part from "a sincere belief that the meteorologically untrained public is in danger of being fleeced by the many fast-talking charlatans who choose weather modification as their game." [19]

Scientific studies of wintertime cloud seeding with silver iodide were summarized in a report submitted to President Eisenhower on Dec. 31, 1957, by the Advisory Committee on Weather Control. The committee said:

> (1) The statistical procedures employed indicated that the seeding of winter-type storm clouds in mountainous areas in the western United States produced an average increase in precipitation of 10 to 15 per cent . . . with heavy odds that this increase was not the result of natural variations in the amount of rainfall.
>
> (2) In non-mountainous areas, the same statistical procedures did not detect any increase in precipitation that could be attributed to cloud seeding. This does not mean that effects may not have been produced. The greater variability in rainfall patterns in non-mountainous areas made the techniques less sensitive for picking up small changes which might have occurred there than when applied to the mountainous regions.
>
> (3) No evidence was found in the evaluation of any project which was intended to increase precipitation that cloud seeding had produced a detectable negative effect on precipitation.
>
> (4) Available hail frequency data were completely inadequate for evaluation purposes and no conclusion as to the effectiveness of hail suppression projects could be reached.

The American Meteorological Society had come to similar conclusions on May 2, 1957. It is clear that the general attitude on weather modification in recent years has shifted from an expectation of immediate practical results to a realization of need for additional research and

[18] U.S. Weather Bureau, *A Summary Report on Progress and Possibilities in Weather Modification* (prepared at request of Senate Select Committee on National Water Resources, October 1959), p. 8.

[19] Archie M. Kahan, "Weather Modification: Panacea or Pipedream," *S.R.I. Journal*, Second Quarter 1959, p. 67.

experimentation. This was, in essence, the position taken at the most recent meeting of meteorologists on the subject.[20]

Attempts to disperse hurricanes by seeding have proved as inconclusive as rain-making efforts. The Weather Bureau in 1947 seeded a hurricane 400 miles off the Georgia coast. Instead of breaking up, the storm turned toward the mainland and smacked into Savannah. Another seeding of a hurricane was made without ascertainable effects in 1959 by the National Hurricane Research Project, a joint Weather Bureau-Department of Defense enterprise. Doubt has been expressed that even the explosion of a nuclear device would disrupt a hurricane system. However, meteorologists persist in trying to find a sure way to rob young storms of their destructive energy.

[20] Skyline Conference on the Design and Conduct of Experiments in Weather Modification, May 1-3, 1959, Shenandoah National Park, Va.